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EVALUATION OF EFFECTIVENESS OF TRAFFIC JAM ABSORPTION DRIVING USING COMPUTER SIMULATION

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Abstract. Traffic congestion absorbing driving is a method of driving at low speed with a larger inter-vehicle distance than surrounding vehicles. This makes it possible to reduce excessive acceleration and deceleration, which is effective in alleviating traffic congestion. The traffic simulation in the sag section confirmed that the traffic congestion absorption driving is effective for traffic congestion mitigation. It was shown that it is possible to increase the average speed in congested sections by means of congestion absorption driving.

1 INTRODUCTION

The number of cars in Japan has exceeded 82 million units until 2022. Increase of the number of vehicles not only causes traffic congestion, but also causes economic losses, traffic accidents, and pollution. Improving traffic congestion is an urgent matter, and there are various efforts to eliminate traffic congestion.

Traffic congestion absorption driving is a vehicle operation method of drivers to prevent traffic congestion. The traffic congestion absorption driving is based on the idea that excessive acceleration and deceleration will be suppressed if the driver runs the vehicle in a relatively large distance between vehicles.

Nishinari et. al. defines traffic congestion absorption driving as “driving techniques to reduce the number of cars to be added to the congestion vehicle platoon”. If the number of cars that add to the end of the congestion vehicle platoon is smaller than the number of cars that pass from the front of the platoon, the length of the congested vehicl platoon is gradually shorter, and as a result, the traffic status is gradually resolved.

On the other hand, there is a concept that the traffic congestion absorption driving is driving technique that does not propagate traffic congestion wave in the backward by adjusting the adjustment speed and distance between vehicles in the traffic congestion section. When decelerating, it slows down more slowly than other vehicles as earlier than other vehicles. When accelerating, it can be realized by using a model that starts acceleration to follow the speed of the vehicle in front.

In the past studies, the effect of traffic congestion absorption driving is discussed only for taking a large distance between cars so that traffic congestion waves do not occur. On the other hand, the idea of "reducing unnecessary acceleration and deceleration smoothly into the forward vehicle and suppressing the waves of traffic congestion" is also pointed out. Therefore, in this study, the effect of traffic congestion absorption driving, which focuses on the characteristics of "traffic congestion wave dose not propage behind by smooth acceleration and deceleration," is quantified in the computer simulation.

2 SIMULATION MODEL

2.1 Vehicle Following Model

A vehicle following model is used as a mathematical model for traffic simulation. In the vehicle following model, the acceleration of the vehicle is determined according to the distance between vehicles, relative speed, and so on.

2.1.1 Chandler model

Chandler model is given by the following equation [1].

$$\ddot{x}_n(t + \Delta t) = \alpha(\dot{x}_{n-1}(t) - \dot{x}_n) \tag{1}$$

where $x_n(t)$ and $x_{n-1}(t)$ denote the position of the vehicke n in the timee t and the position of the vehicle $n-1$ just before the vehicle n, respectively. . $\dot{x}_n$ and $\ddot{x}_n$ represent the first and second derivatives the time t. Therefore, $\dot{x}_n$ and $\ddot{x}_n$ are the speed and the accleration of the vehicle, respectively. In addition, α represents sensitivity, and ΔT represents the delay time in response. Since there is a relative speed $\dot{x}_{n-1}(t) - \dot{x}_n(t)$ in the model, this model controls the acceleration according to the speed difference between the vehicle in front of the vehicle.

2.1.2 Helly Model

Helly model is given by the following equation [2].

$$\ddot{x}_n(t + \Delta T) = \alpha(\dot{x}_{n-1}(t) - \dot{x}_n(t)) + \beta(x_{n-1}(t) - x_n(t) - D_n(T)) \tag{2}$$

where α and β denote the sensitivity for relative speed with the previous vehicle and the sensitivity for the distance between vehicles just before. $D_n(t)$ is a function that gives an ideal inter-vehicle distance, which is defined as

$$D_n(t) = a + b\dot{x}_n(t) + c\ddot{x}_n(t) \tag{3}$$

where a, b and c are constants.

Table 1: Simulation Condition

Variable	value
Time step	$0.1s$
Ideal car head time	$1.5s$
Car length	$6m$
Max of velocity	$110km/h$
Enter velocity	$80km/h$
Road length	$15000m$
Sag section	$10000m$ to $11000m$
Deceleration in sag section	$-0.587m/s^2$
Minimum velocity in sag section	$40km/h$
Car number causing traffic jam	1
Car control model	Helly model
α in Helly model	0.1 to 0.8
β in Helly model	0.1 to 0.8

2.2 Experimental Condition

The road length of the experimental environment is 15000m, and the sag section shall be 10,000 to 11000m. The slope of the sag section is referred to as the sag section between Uenohara IC and Sedaizaka IC [3]. The negative acceleration a_i is given by the following equation from the slope of this sag section.

$$a_i = 9.81 \times \sin(\tan^{-1}(6.0/100)) = -0.587m/s^2 \tag{4}$$

The number of time steps is 0.1s. The size of the vehicle shall be 6m assuming a normal car, and the ideal car time for each vehicle shall be 1.5 s. The inflow speed of the vehicle is 80km/h, and the maximum speed is limited to 110km/h. In addition, the deceleration amount due to traffic congestion cars is up to 40km/h from the actual measurement data [3, 4]. After passing the sag section, traffic congestion cars become the same driving rules as ordinary vehicles. Helly model is used as the vehicle following mde for general vehicles. Then, the values of the sensitivity α and β are assigned for each vehicle randomly from 0.1 to 0.8.

The experimental conditions are summarized in Table 1.

2.3 Control algorithm of Vehicle According To Traffic Congestion Abserption Driving

When a vehicle runs according to traffic congestion absorption driving, the speed control of the vehicle is divided into two stages regarding the starting point of traffic congestion absorption driving (p_j km point). The first is the case where it runs before the starting point, and the second is when it runs after the starting point. In addition, a conventional study has confirmed that traffic jams are absorbed by absorbing driving from about 5 km in front of the bottleneck section. Therefore, in this study, p_j is defined as an arbitrary value that is several km in front of the sag section.

Table 2: Simulation Parameter

Variable	value
Number of trials	10
p_j	$7000m$
d_i	$150m$
a_i	$0.35(1/d_i)$
a_d	0.05
a_a	0.8

Before the vehicle passes through the starting point, the vehicle speed is controlled according to the driving rules (Helly model) of the general vehicle.

After the vehicle passes through the starting point, it is controlled so that the distance between vehicles is larger than the surrounding vehicles. Specifically, the speed control of the vehicle is controlled according to the Helly model. By taking the ideal inter -vehicle distance d in the Helly model before the vehicle passes through the starting point, the distance between the vehicle in front of the vehicle is expanded. If the vehicle in front of a vehicle decelerates due to traffic congestion, the acceleration is determined by reflecting the relative speed with the front vehicle in the vehicle based on the Chandler model.

If the vehicle in front of a vehicle is accelerating and faster than the vehicle, the vehicles accelerates according to the Chandler model with the relative speed with the front vehicle. In this study, the sensitivity of the vehicle according to the traffic congestion absorption driving is defined appropriately so that it does not collide with the forward vehicle.

3 COMPUTER SIMULATION

3.1 Simulation Setting

It is assumed that the first vehicle of a vehicle platoon can cause traffic congestion. If there is no vehicle according to the traffic congestion absorption driving in the platoon, the simulation result shows that the 180th vehicle from the leading vehicle of the platoon may decelerate at -0.5 m/s^2. Therefore, a vehicle according to the traffic congestion absorption driving shall be placed evenly between the first and the 180th vehicles. It is known that the deceleration of the brake for the vehicles is generally below $-0.5m/s$. Vehicles that decelerate by the brake pedal are counted from the first vehicle to the 180th vehicle [6]. For example, if there is one vehicle according to traffic congestion absorption driving, the vehicle shall be the 90th vehicle. If there are two vehicles according to traffic congestion absorption driving, they shall be the 60th and 120th vehicles, and in the case of three vehicles according to traffic congestion absorption driving, they shall be the 45th, 90th, and 125th vehicles.

In order to evaluate the experimental results, the passing time of each vehicle from $8000m$ to $11000m$ and the maximum deceleration of each vehicle are observed. The vehicles to be evaluated shall be from the first vehicle to the 341st vehicle of the vehicle platoon. The above experimental parameters are shown in the Table 2.

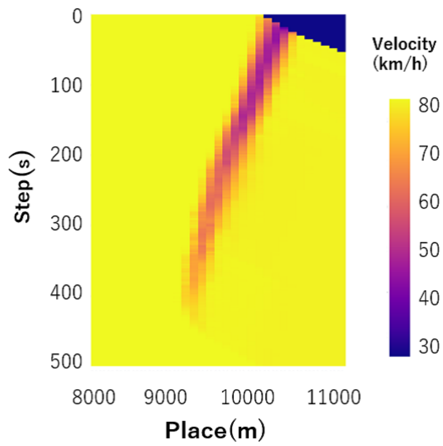

Figure 1: Average speed of traffic flow in case of no vehicle according to traffic congestion absorption driving

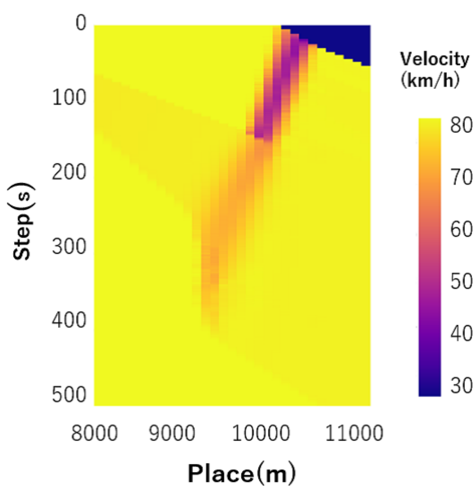

Figure 2: Average speed of traffic flow in case of one vehicle according to traffic congestion absorption driving

3.2 Simulation Results

Figure 1 shows the average speed of traffic flow when there is no vehicle according to traffic congestion absorption driving. Figure 2 shows the section average speed of traffic flow, which contains one vehicle according to traffic congestion absorption driving. In these figures, the horizontal axis indicates the coordinates, and the vertical axis indicates time. One square area indicates a region of 100m width road within 1s. The color of each area indicates the average speed of vehicles existing in that area.

Figure 1 shows the simulation result when there is no vehicle according to traffic congestion absorption driving. In Fig.1, in purple areas that extend to the lower left from Place = $10000m$ with Step = $10s$, the average speed is lower than the surrounding area. Figure 1 indicates that the purple area exists in the following vehicles when only ordinary vehicles run, and that the traffic congestion generated at the front vehicle is transmitted to the following vehicles. The congestion waves are gradually weakened and propagated to the rear vehicle, and eventually disappeared around $400s$. This is probably because the inflow amount is constant and the distance between vehicles is not closely clogged.

Figure 2 shows the simulation result when there is one vehicle according to the traffic congestion absorption driving. Figure 2 shows that the average speed of the traffic congestion section has improved than in Figure 1. The speed decreases to around 50 km/h due to traffic congestion, but has recovered to around 70 km/h as a vehicle according to traffic congestion absorption driving passes. This indicates that the behavior of vehicles according to traffic congestion absorption driving has alleviated traffic jams. However, it can be confirmed that the speed recovery by the traffic congestion absorption driving does not reach the speed before the occurrence of traffic congestion. In order to increase the distance between the surrounding vehicles, vehicles according to traffic congestion absorption driving will start deceleration in front of the traffic congestion section. Therefore, it can be seen that the vehicle after the vehicle has also had small deceleration before the traffic congestion section. In existence of vehicles according to traffic congestion absorption driving, the following vehicle has a shorter car distance, so that the wave of the speed after recovery is transmitted to the rear vehicle without attenuating.

Consider the effect of increasing the number of vehicles according to traffic congestion absorption driving from one to three. Figures 3 and 4 show the section average speed of traffic flow when two and three vehicles run according to the traffic congestion absorption driving, respectively. The purple area indicating the traffic congestion is smaller as the number of vhielces accrding to the traffic congestion abserption driving increases.

From the above results, it was confirmed that traffic congestion absorption driving could reduce passing time in traffic congestion sections and reduced maximum deceleration. This indicates that traffic congestion absorption is effective in relieving traffic congestion.

4 CONCLUSION

The purpose of this study is to discuss how vehicle behavior according to traffic congestion driving can help relieve traffic congestion. For this reason, the behavior of vehicles in accor-

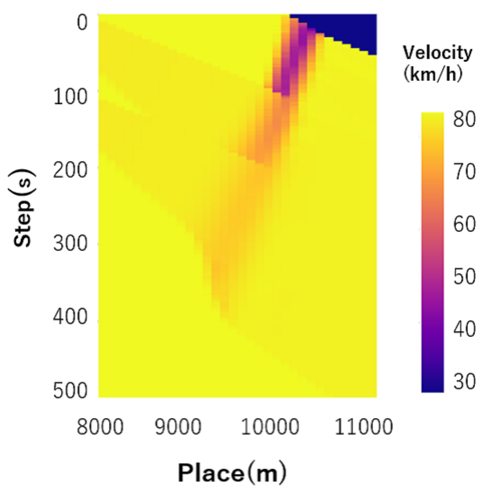

Figure 3: Average speed of traffic flow in case of two vehicles according to traffic congestion absorption driving

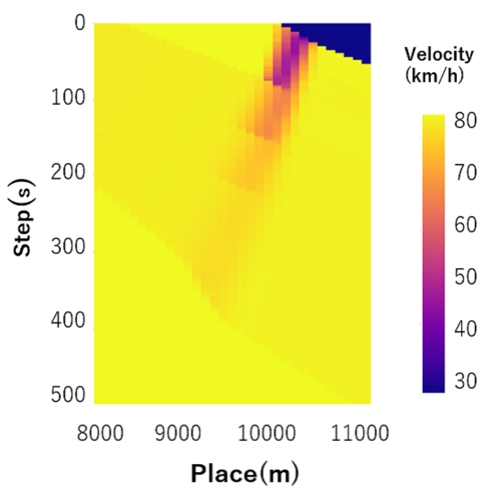

Figure 4: Average speed of traffic flow in case of three vehicles according to traffic congestion absorption driving

dance with traffic congestion was defined by a mathematical model and computer simulation was applied to the vehicles running through the sag section, and the effectiveness of traffic congestion absorption driving was discussed.

The simulation result indicated that the average speed of vehicles in the traffic congestion section increases when vehicles drive according to traffic congestion absorption. As a result, it was confirmed that traffic congestion absorption was effective in relieving traffic congestion in the sag section.

Future issues can be summarized as follows. There is a large space in front of a vehicle running according to traffic congestion absorption driving. If the driving lane is a two -lane road, there will be vehicles interrupted in the large space, causing more complex traffic congestion. In the future, it is necessary to extend the traffic simulation to a two -lane road and demonstrate the effect of traffic congestion absorption and driving in a situation where interrupts occur.

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